conical case, the analytical solutions are also available in Ref. 2. The technique presented herein can be applied to an axisymmetric surface of infinite length as well as that of finite length. It can also be applied to the segmentation of a surface in case the shape factor variation with longitudinal distance is desired.

References

[1] Hamilton, D. C. and Morgan, W. R., "Radiant-interchange configuration factors," NACA TN2836, Purdue Univ. (December 1952).

[2] Morizumi, S. J., "Analytical method of determining shape factor from a surface element to a conical surface," Space Technology Labs. Internal Memo. 62-9721. 4-78 (October 1962).

Effect of Boundary-Layer Removal on High Velocity Flame Stabilization

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THE present investigation is concerned with the influence of the boundary-layer structure, as exemplified by the measured velocity profiles and boundary-layer mass flow rate, on flame stabilization utilizing the recessed wall flame holder. The feasibility of recessed wall stabilization has been demonstrated,[2] and a qualitative investigation of the influence of boundary-layer thickness on flame stabilization with the recessed wall flame holder has been reported.[4]

The impetus for the present investigation was the studies by Cheng and Kovitz[1] and Marble and Adamson[3] on mixing and ignition of a combustible mixture in the laminar wake of a flat plate. The Marble and Adamson investigation considered both streams to have initially uniform velocity profiles, whereas the Cheng and Kovitz analysis considered the effect of initial velocity distributions in the two streams. It was found that the inclusion of nonuniform initial velocity boundary layers affects considerably the temperature and concentration profiles downstream of the initial contact point.

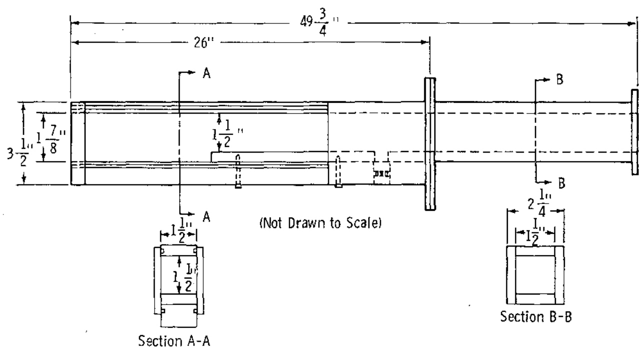

Fig. 1 Detail of test section.

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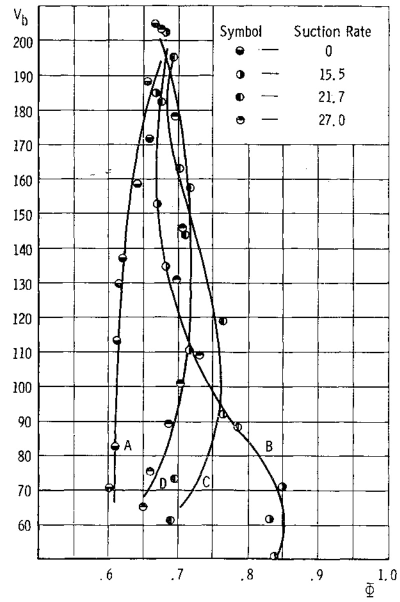

Fig. 2 Blowoff curves: *A*, no suction; *B*, suction rate of 15.5 standard ft³/min; *C*, suction rate of 21.7 standard ft³/min; and *D*, suction rate of 27.0 standard ft³/min.

In the present investigation, the flame stabilizer is the recessed wall and the mixture is a premixed, homogeneous mixture of air and propane. A suction slot of variable width is provided upstream of the point of stabilization, and the boundary-layer structure at the point of stabilization is varied by boundary-layer suction through the suction slot. The suction flow is metered, and the geometry of the apparatus is shown in Fig. 1.

Velocity profiles were measured in the cold flow boundary layer at the stabilization point using a flow corporation model HWB2 hot wire anemometer and a 0.00035-in. tungsten wire. Velocity profiles and blowout curves were obtained without suction, and blowout curves were obtained with three different suction rates. The lean blowoff curves with and without suction are shown in Fig. 2.

From the measured velocity profiles, the boundary-layer mass flow rate without suction was calculated by graphical integration of the velocity profiles. Knowing the boundary-layer flow without suction, the suction rate was then normalized by defining a parameter R as the ratio of the suction flow rate to the boundary-layer flow rate at the flame holder in the absence of suction. The lean blowoff data of Fig. 2 could then be correlated by plotting $\Phi s/\Phi 0$ against R with velocity as the parameter where $\Phi s/\Phi 0$ is the ratio of the equivalence ratio at blowoff with suction to that at blowoff without suction at the same value of blowoff velocity (taken as the mean velocity of the cold flow preceding the point of stabilization). This correlation is shown in Fig. 3.

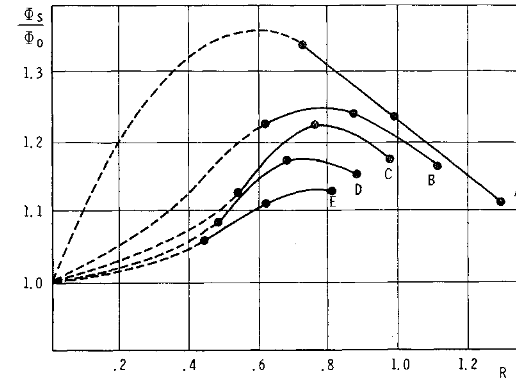

Fig. 3 Quotient of equivalence ratios with and without suction vs ratio of suction rate to boundary-layer flow. *A*, V_b = 80 fps; *B*, V_b = 100; *C*, V_b = 120; *D*, V_b = 140; and *E*, V_b = 160.

From Fig. 3, the following conclusions can be drawn relative to the recessed wall flame holder operating with lean mixtures:

1) For a given mean velocity, the effect of boundary-layer removal on blowoff is to cause blowoff to occur at a higher equivalence ratio than the value at which blowoff occurs without suction.

2) For a given mean velocity, the blowoff equivalence ratio increases with suction rate to a maximum value and then decreases.

3) For a given mean velocity, the maximum equivalence ratio occurs at a suction rate less than that required for complete boundary-layer removal. The maximum equivalence ratio occurred at a suction rate of 70 to 75% of the boundary-layer flow.

4) The effect of boundary-layer removal on stabilization decreases at higher velocities.

References

[1] Cheng, S. I. and Kovitz, A. A., "Ignition in the laminar wake of a flat plate," *Proceedings of the Sixth Symposium (International) on Combustion* (Williams and Wilkins, Baltimore, Md., 1956), Vol. 6, pp. 418–427.

[2] Huellmantel, L. W., Ziemer, R. W., and Cambel, A. B., "Stabilization of premixed propane-air flames in recessed ducts," Jet Propulsion **27**, 31–34 (1957).

[3] Marble, F. E. and Adamson, T. C., "Ignition and combustion in a laminar mixing zone," Jet Propulsion **24**, 85–94 (1954).

[4] Snyder, W. T., "Influence of approach boundary layer thickness on premixed propane-air flames stabilized in a sudden expansion," Jet Propulsion **28**, 822–825 (1958).

Self-Preserving Fluctuations and Scales for the Hypersonic Turbulent Wake

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Introduction

If the electric field incident upon each point of the underdense turbulent wake is assumed to be unperturbed by the scattered electric field (an assumption that has been referred to as a Born approximation), a knowledge of the statistical properties of the wake suffices to enable an approximate calculation of radar return.[1–4] Required is the double correlation function †$Q = \overline{\delta\eta(\mathbf{x})\delta\eta(\mathbf{x}+\mathbf{r})}$ of the passive field of dielectric constant fluctuations $\delta\eta$ at all points in the wake. This (scalar) quantity is generally a function of the vector position quantities $\mathbf{x}$ (measured, e.g., from the field source as origin) and $\mathbf{r}$ (measured from the point $\mathbf{x}$). For a homogeneous isotropic field, only the scalar polar radius r enters as argument. Alternatively, the (scalar) three-dimensional Fourier transform $E(\mathbf{k})$ of the correlation function may by specified; for an isotropic field, it is a function of the (scalar) wave number magnitude k. Because of the spherical symmetry of the isotropic field, it is sometimes useful to define a quantity $\hat{E}(k) = 4\pi k^2 E(k)$, which may then be interpreted as the density per unit thickness of $E(k)$ on a spherical shell of radius k in wave number space, i.e., as the line density along coordinate k.[5] As an example of the functional form that E may assume, consider the interpolation formula suggested by Hinze[6] for an isotropic scalar field (in analogy to a suggestion by von Kármán for velocity fluctuations):

$$\hat{E}(k) = 0.8\eta'^2\Lambda(k\Lambda)^2[1 + (k\Lambda)^2]^{-11/6} \quad (1)$$

where Λ is approximately the integral scale

$$\Lambda \approx \eta'^{-2}\int_0^\infty Q(r)dr$$

and η' the rms fluctuation level of η. This expression exhibits the proper k^2 behavior of an isotropic scalar field for small k and the Kolmogoroff $k^{-5/3}$ behavior for large k; the latter is appropriate‡ over a range of wave numbers for high Reynolds number (e.g., see Ref. 7). The use of a typical relation as the foregoing reduces the calculational problem to a determination of the variation of η' and Λ in the wake. In this note, the consequences of the assumption of a self-preserving fluctuation field will be examined for the fluid mechanical variables of a hypersonic wake. This useful assumption enables the fluctuating field to be calculated in terms of mean flow properties and provides a model that is expected to be valid at large distance from the body. However, at the present time, only rough inferences[8] may be made concerning the dielectric constant fluctuation and its relation to the fluid mechanical fluctuations; this important connection is beyond the scope of the present note.

Self-Preserving Flow

The concept of a self-preserving turbulent field is based on the presumption that the time required for the mean flow to vary, τ_D, is longer than a characteristic time for "adjustment" of the fluctuating field to a change in the mean flow τ_a. An often observed phenomenon in a turbulent field is that the time scale for "energy containing" eddies to interact and transfer their energy to higher wave numbers is of the order of the period of these eddies.[5] The energy containing eddies have a period of $\approx k_1 y_f/(U_0 - U_f)$, where $0.1 < k_1 < 1$. The time required for the mean flow to vary is y_f^2/ϵ. Taking $\epsilon = K(U_0 - U_f)y_f$ then the ratio of these times is $\tau_a/\tau_D = Kk_1$. Since $10^{-2} < K < 10^{-1}$,[9,10] τ_a/τ_D is smaller than unity, suggesting self-preservation for the energy containing eddies.

The detailed results of Townsend for an incompressible cylinder wake indicate that the far wake is indeed accurately self-preserving.[9] Whether a similar result will hold for a compressible axisymmetric wake remains to be shown. As in the case of the incompressible wake, a double structure is likely, i.e., small-scale high-intensity eddies embedded in slowly interacting low wave number eddies. The foregoing estimates, which apply to either compressible or incompressible flow, suggest that the large eddies do not maintain their identity very far downstream.§ In fact, the model of Townsend is that of local equilibrium of large eddies; these eddies "are not permanent structures, new ones arising as old ones disappear" (Ref. 6, p. 440). Further, their energy content, although not negligible, has been found to be small (less than 20% of total[9]). Thus, if one is concerned with the underdense far wake, local self-preservation may be reasonable as a rough approximation. It is at least interesting to examine the consequences of this assumption for typical hypersonic wakes of interest.

Fluctuation Levels

If the velocity fluctuation field is self-preserving, then by definition $(U'/U)^2 = a[(U_f - U)/U)]^2$, where a is a constant. Since $U \approx U_f$ and the stagnation enthalpy is con-

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† Bars over quantities refer to time or ensemble averaged properties. Primes refer to rms values. Subscripts 0 and f denote values on wake axis and at wake edge.

‡ The Reynolds number may not be sufficiently high for cases of interest.[8]

§ Estimates of the effect of finite time-constant mixing have recently been made by Proudian and Feldman.[11] A comparison of limiting cases has been carried out by Lin and Hayes.[12]